THE CLIMATE OF THE HISTORIC PAST.

By ELLSWORTH HUNTINGTON. Dated New Haven, Conn., January 18, 1909.

[*Continued from the Monthly Weather Review for November, 1908.*]

PART II. THE NEW WORLD.

The climatic history of the New World appears to have been essentially the same as that of the Old World. The marked uniformity in the order of the main events of the glacial period on both sides of the Atlantic Ocean has led geologists to the conclusion that the Eastern and Western hemispheres were subjected to the various phases of this period at the same time. This conclusion is strengthened by the absence of any plausible theory upon which the phenomena of glaciation can be explained without an assumption involving such synchronism. In the Southern Hemisphere the glacial period produced the same succession of phenomena as in the Northern, but there is at present no general agreement as to whether a given phase, glacial or inter-glacial, occurred simultaneously or alternately, on both sides of the equator. On the whole, however, there seems to be a growing tendency toward the opinion that the events of the glacial period occurred simultaneously thruout the world.

Turning to the climate of modern time, it appears from the work of Brückner[1] and others that, altho there are certain oceanic and tropical regions of permanent exception, the continental regions of the earth as a whole pass almost simultaneously thru certain brief climatic cycles. Brückner's cycle of thirty-five or thirty-six years stands as the type of the changes in climate which are in progress at the present time. The dry phase of the cycle is marked by comparative aridity not only in North America and Eurasia outside the Tropics, but in similar continental regions of the Southern Hemisphere.

If it be true that glacial cycles and Brückner cycles affect all the continental regions of the Northern Hemisphere, and possibly of the whole world at once, it is probable that the intermediate cycles of which evidence is found in Asia affected the Western Hemisphere as well as the Eastern. There is distinct ground for believing this to be the case. Inasmuch as the historic period in the New World is far shorter than in the Old, there naturally is correspondingly less opportunity in the New to connect human events with any changes of climate of which evidence may be forthcoming. The American student is likely to turn first to Great Salt Lake to see if it has varied in size during the last two thousand years. Unfortunately the basin of the lake contains no ruins left by ancient man; and the known history of the region extends over only a century. Therefore, Great Salt Lake must be dismissed until further knowledge is obtained. It presents no known evidence either for or against a change of climate during historic times, altho it is well known that in the glacial period its size increased enormously.

The cliff-dwellings of the Zunis.—Altho North America presents no very strong evidence of climatic change, the Zuni ruins and the history of the city of Mexico deserve some discussion before the much stronger evidence in South America is described. South and southeast of Great Salt Lake the cliff-dwellings of the Zunis present a type of evidence comparable to that of the ruins of central Asia. Many dwellings, as is well known, are located in places where the supply of water seems utterly insufficient for the number of people who appear to have lived there. Students have attempted to explain this by supposing that the population at any one time was very small; they assumed that generation after generation went to the trouble of building new houses, leaving the old ones empty altho in perfect repair. An explanation of the apparent lack of water has been derived from the fact that in a few cases concealed springs have been found. From this fact it has been inferred that when the Zunis left New Mexico and Arizona they buried numerous springs, thus causing a fairly large supply of water to vanish without leaving a trace. Other ingenious hypotheses have been advanced, but the theory of changes of climate has in most cases been sedulously avoided, altho it fully explains all the facts and there seems to be nothing to oppose it.

The City of Mexico and Lake Tezcuco.—The City of Mexico lies 7,400 feet above the sea near the salt lake of Tezcuco, in a basin whose general physical features, apart from size, closely resemble those of the large basins of Lop and Seyistan. Historic records of the country extend back 600 years. During that time there appears to have been a slight, but appreciable change of climate in Asia, as has been shown in Part I, and the same seems to be true of Mexico. The evidence is somewhat masked by the fact that the natural course of events has been interrupted by various works of man, such as the dykes, canals, and tunnels, which have been built at various times since 1446 to regulate the waters of Tezcuco and its three tributary lakes. Nevertheless, there have been certain periods when nature has triumphed over human endeavor, and the waters have returned to the level which they would naturally occupy if man had never interfered. A comparison of the two chief epochs of this sort affords ground for the belief that the climate of North America has passed thru fluctuations like those which Asia has experienced.

The great authority on early Mexico is Humboldt, whose "Essai Politique sur la Royaume de la Nouvelle-Espagne" was published in 1811 as the third part of the "Voyage de Humboldt et Bonpland." Later and less authoritative writers such as Prescott[2] and Romero[3] follow him closely, adding little that is new. Humboldt specifically states his belief that the climate of Mexico in his day was more arid than it was at the time of the founding of the capital in 1325 A. D. He attributes the change in part to meteorological causes whereby evaporation has exceeded precipitation, and partly to the reckless destruction of forests by the Spaniards. He is sure that the level of Lake Tezcuco has fallen, thru natural causes as well as thru the works of man, and cites this fact as the chief evidence of a change of climate. In attributing the fall of the lake to the destruction of forests, he fails to consider that the removal of a protective covering of plants from the mountains might cause the summer rains to rush rapidly down the steep slopes which surround the basin, and thus decidedly raise the maximum level of high water, even tho the mean level might be lower than formerly.

The two periods at which it is possible to make a fair comparison of the earlier and later conditions of Lake Tezcuco are the interval from the foundation of the City of Mexico in 1325 to the Spanish conquest in 1520, and the interval from the great flood of 1629 to the middle of the next century, or 1755. The Aztec founders of Mexico, like most of the world's great races, came from the north. After a century or more of adventurous wanderings, enlivened by the vicissitudes of war, conquest, and slavery, they at length reached the shores of Tezcuco in 1325 A. D. Hoping for peace and safety, the Aztecs located themselves on some small islets several miles from the shore. There they laid the foundations of the present proud City of Mexico by sinking piles into the marshy shallows and erecting upon them light huts of reeds and rushes above the reach of the water. During the succeeding century, according to Humbold's lucid account, the city grew and prospered and its rule spread over the neighboring regions. It was still an island city with houses on piles, with canals instead of streets in many cases, and with canoes in place of beasts of burden. Sometimes it suffered when the lake rose more than usual; once, near the end of the fifteenth century, the water fell so

[1] E. Brückner: Klimaschwankungen seit 1700. Vienna. 1890.

[2] William H. Prescott: History of the Conquest of Mexico. Bk. I, III, IV.

[3] M. Romero: Geographical and Statistical Notes on Mexico. New York. 1908.

low that the city was in distress because canoes could not come to it with supplies of food from the country round about. In 1446 the first dyke was built to keep the water from the city in times of flood; but when Cortez came to Mexico in 1519 the capital was still a western Venice. He describes it as located on an island two leagues from the mainland. In order to besiege it effectively he was obliged to build brigantines, and in these he was able to sail completely around the city, except for a small distance on the southwest side toward Chapultepec, where the water was too shallow. The small boats engaged in ordinary traffic sailed everywhere, not only on Tezcuco, but on the other lakes and on the connecting rivers.

A century after the Spanish conquest the condition of the City of Mexico had changed. It had ceased to be an island, the canals had become dry; and wheeled vehicles had taken the place of canoes. This result was due in part to the construction of additional dykes, but nature apparently had been the main agent in the matter. Such seems to have been the opinion of Torquemada, a monk who lived in Mexico from the middle of the sixteenth century to the beginning of the seventeenth. He says, according to Prescott (page 33), that:

> As God permitted the waters which had once covered the whole earth to subside, after mankind had been nearly exterminated for their iniquities, so He allowed the waters of the Mexican lake to subside in token of good will and reconciliation after the idolatrous races of the land had been destroyed by the Spaniards.

About the time of Torquemada's death there occurred one of the periods of high water which, at that epoch, still periodically reduced the city to a partially inundated condition. To prevent such occurrence in the future a tunnel was built to carry off the surplus water of the Cuautitlan River. It might be supposed that after the construction of the tunnel the lake would never return to its natural condition. In 1629, however, during a season of uncommonly large floods the tunnel was stopped up completely. The City of Mexico was flooded for a time, but after a period of extraordinarily rainy years lasting till 1634, it became dry once more, altho neither the tunnel nor the old dykes were in a condition to prevent the rise of the water. Again, from 1675 to about 1755, the tunnel was closed completely, being filled with earth for an unknown distance. At the same time also the dykes were in poor repair, breaking whenever the water rose higher than usual. Nevertheless the city continued to stand on dry land. Sometimes, to be sure, a year of exceptional rains caused the water to rise sufficiently to flow into some of the streets, but not enough to do any serious damage. In other words, at the end of the seventeenth and the beginning of the eighteenth centuries the City of Mexico stood normally on dry land even without the aid of dykes or tunnels. Two or three hundred years earlier, on the contrary, the city was nominally a swamp island.

Further careful study is necessary before the cause of this change can be asserted positively. It is possible that the level of the ground in some parts of the city may have been artificially raised to an extent unknown by Humboldt. It is also possible that he, being prepossessed by an idea, may have given undue weight to phenomena which are undoubtedly much smaller and less significent than those in Asia. The level of Lake Tezcuco to-day depends entirely upon the works of man. However, human intervention does not seem to have been accountable for all of the fall in level between 1325, A. D., and the days of Humboldt. It is at least a fair working hypothesis that there has been a very slight permanent change of climate. Such an hypothesis seems to fit all the facts perfectly, but it can be proved or disproved only by further most painstaking investigation.

Evidence of change in South America.—Evidence as to the climate of the historic past is more abundant in South America and more conclusive than in North America. This is largely because the population of South America previous to the days of Columbus was more numerous and more civilized than that of North America, taken as a whole. Various authors have commented briefly upon this subject, and Bowman, in a paper read before the Association of American Geographers in December, 1907, has brought the subject into prominence by comparing the observations of Darwin and Moreno with his own important discoveries.[4]

The arid regions of South America consist of three chief parts. (1) In the first place a long narrow strip of desert extends along the western coast of the continent for about 30 degrees of latitude, from latitude 3° S., or a hundred miles south of Guayaquil to 32° S., or almost to Valparaiso, in Chile. Its dryness is due to the fact that it lies on the lee side of the lofty Andes in the zone of the southeast trade-winds, which lose their moisture on the east side of the mountains and become warm and very dry as they descend to the sea on the west. (2) The second extremely dry region lies east of the Andes and extends from about latitude 30° S. to nearly 50° S. Its aridity is due to the fact that it is located in the zone of prevailing strong westerly winds, which deposit their moisture in Chile, on the west side of the Andes, and accordingly are very dry when they pass over into Argentina and Patagonia. (3) The third region lies between the other two and extends roughly from latitue 15° S. to 30° S. It consists chiefly of a high plateau in Bolivia, within which lies Lake Titicaca and a great number of small salt lakes without outlets. Its aridity is due partly to its location in the subtropical zone of high pressure and descending, drying air and partly to the fact that it is entirely surrounded by lofty mountains which cut off much of the moisture which might otherwise be available. In all three of these dry regions of South America certain facts have been described which seem to indicate desiccation.

(1) *Jefferson's observations on the terraces of Peru.*—One of the first points on the west coast of South America at which the traveler arriving from the north finds himself face to face with the problem of desiccation is Lima, the capital of Peru, 12 degrees south of the equator. No one seems to have investigated the subject of desiccation critically in this region, altho numerous travelers comment upon the abundant and interesting evidences of more extensive cultivation in the past than in the present. The following statement, which has been kindly contributed by Prof. Mark Jefferson shows the nature of the phenomena and the importance which they may possess as indications of a most remarkable change in agricultural conditions either because of a change in climate or for some other reason, such as political upheavals, which, however, scarcely seem competent to produce all of the results described. Professor Jefferson's observations were made at a time when he was a keen-eyed young traveler rather than the careful scientist that he has now become; they deserve to be put on record, not only because of their intrinsic value, but also in order to stimulate further investigation. He writes as follows:

> The rainfall of Lima is very slight, amounting to only 46 millimeters (1.8 inches) as the average of six years' observations, according to Voss.[5]
>
> In estimating the significance of the phenomena here described it should be borne in mind that the terraces described below lie higher than Lima, and hence have a rainfall somewhat greater than the figure given above, altho still extremely meager.
>
> It is commonly said there, or was said at the time of my visit in 1886, that it rarely rains; and the wet sidewalks seen in the morning were ascribed to heavy dews. The triangle of cultivated land between Lima and Callao has its water from the river Rimac, and so do the fields on the valley floor that one follows, stream upwards, in making the railroad trip to Oroyo, up in the Andes. But the valley walls, which are all seamed with little terraces as the picture shows, are quite devoid of means of irrigation. The front of each terrace is a dry stone wall, and

[4] See the Geographical Journal. vol. 33, 1909. Man and Climatic Change in South America, by Isaiah Bowman.

[5] Die Niederschlagsverhältnisse von Südamerika. Ergänzungsheft 157 zu Petermanns Mitteilungen 1907.

the width is rarely so much as seven or eight feet. They were all dry, barren, and unused when I saw them in 1886. At the time when they were cultivated they must have depended upon rainfall, for there was no sign that irrigation brought water to them, nor could that have been done profitably with patches so small. In Lima, tho it rarely rains, the sky is often thick and hazy. An ascent of a few thousand feet up the mountain railway brings one into showers, there almost as incessant as the drought below. The present drought on the terraces seems to be due to a rising of the rain belt since Inca days.

(2) *Darwin's observations in Chili.*—Twelve hundred miles south of Lima, Darwin, the first of the authors referred to by Bowman in the article cited above, found phenomena which, like those of Lima, lie in the arid strip on the western flank of the Andes and suggest desiccation. He has described them in his classic volume, "The Voyage of the Beagle."

While traveling high among the Andes on their western side, about 30 degrees south of the equator, near the southern end of the sterile desert of northern Chile, Darwin came upon ruins in several places which are now uninhabitable. "Traces of Indian habitations have been discovered," he says (p. 409, edition of 1839), "in many parts of the Cordillera where the land is as utterly unfit for any kind of cultivation as it is near the Tambillos or Puente del Inca [two places where Darwin saw ruins]. * * * I have almost been inclined to speculate on the possibility of a small change of climate. In the Despoblado (uninhabited valley), near Copiapo, at a spot called Punta Gorda, I saw the remains of seven or eight square little rooms which were of a similar form with those at the Tambillos. They were situated in the most conspicuous and defenceless position, at the bottom of a flat, broad valley. There was no water nearer than 3 or 4 leagues, and that only in very small quantity, and bad; the soil was absolutely sterile; I looked in vain even for a lichen adhering to the rocks. At the present day, with the advantage of beasts of burden, a mine, unless it were very rich, could scarcely be worked there with profit. Yet the Indians formerly chose it as a place of residence! If at the present time two or three showers of rain were to fall annually, instead of one during as many years as is now the case, a small rill of water would in all probability be formed in this great valley, draining a mountainous country; and then by irrigation, the method which was formerly so well understood by the Indians, the soil might easily be rendered sufficiently productive to support a few families."

In explanation of the inferred change of climate, Darwin speculates on the possibility of its having been due to an uplift of the mountains, but is inclined to reject this hypothesis because of the length of time required for a movement of the land sufficient to produce the observed results. He dismisses the question with the suggestion that in some places the movements of the earth, which give rise to earthquakes, may have altered the courses of streams. He comes to no conclusion as to the cause, altho he seems to have little doubt as to the fact of change.

(3) *Moreno's observations in Argentina and Bolivia.*—Two or three hundred miles southeast of the district of which Darwin writes, and on the other side of the Andes in Argentina, Moreno, the second author cited by Bowman, describes other evidences of a change of climate, located in the second of the great dry regions of South America.[6]

In the gorges of the east side of the Andes between Valparaiso and Mendoza, there exist, he says—

extensive ruins where to-day life is extremely difficult or impossible during a great part of the year. * * * Extensive irrigation works are to be seen where to-day one could not possibly find a drop of water, showing that the climatic conditions of these regions have changed and that the waters must have diminished. It is known that a century ago the small lakes of Guanacache, between San Juan and Mendoza, were much more extensive, and that the Indians navigated them in the same manner as they navigate Lake Titicaca at the present time.

[6] F. P. Moreno: "Notes on the anthropogeography of Argentina." Geographical Journal, 1901, 18, p. 581 ff.

Moreno mentions other regions where similar phenomena are found. For instance, four or five hundred miles northeast of Mendoza, in latitude 27° S., the ruins of Pucara, in northwestern Argentina, lie on the southeastern slope of the plateau of Bolivia. Here—

the remains of walls and agricultural grounds show that the population numbered tens of thousands. To-day the waters of the valley are scanty and used only by a few descendants of the natives, possessing only a few goats and a little maize. In former times rains must have been frequent and water more abundant than it is to-day, as there are still visible small grounds in the rocky slopes which have been cultivated by natural supplies and not by irrigation, which would have been impossible.

This last statement, as Bowman points out, is particularly significant. The fact that certain areas which were once cultivated, are so located that irrigation would there be impossible even if there were a sufficient water supply shows that there must once have been rain enough to support crops. The fall of such rain must have been frequent enough to provide water not only for the unirrigated areas, but also for the large settlements whose ruins now remain.

In the region of Pucara and in the southern portion of the Bolivian plateau a little farther west, Moreno cites still further evidence of a similar nature to that given above. Near Pilchias and Constancias, two mining settlements, the miners discovered "old settlements and burial grounds in districts where now it is necessary to carry water for drinking purposes."

(4) *Bowman's observations on the old roads of Lake Huaco.*—The evidence of climatic change adduced by Bowman is of quite a different nature from that given by Darwin and Moreno. Seven hundred miles north of Darwin's region and still farther from the first of Moreno's sites, the basin of Huasco lies on the western edge of the Bolivian plateau in latitude 21° S. at an elevation of 13,000 feet above the sea. The basin is about 14 miles long from north to south, and 8 miles wide from east to west. Its floor is occupied by a shallow salt lake, which was formerly larger than it now is, as appears from the saline deposits which surround it, and from old beaches which lie at various levels above the salt plain. The lake has no outlet and changes in its level must be due to variations in the inflow or in the rate of evaporation. The surrounding country is uninhabited and there is not the slightest reason to believe that former tributaries of the lake have been diverted. Therefore changes in the water level must, it would seem, be ascribed to changes in precipitation or in evaporation, that is to changes in climate.

The west side of the Huasco basin is bounded by a steep scarp at the foot of which several springs of water flow forth. Near the springs stand a number of corrals used by travelers along the various llama trails which radiate from this point. One of the trails runs south and east around the southern side of the lake to the southeast corner of the basin. It follows the shortest possible line from spring to spring, a line which has the further advantage of lying as close to the lake as possible, in the narrow strip where alone grass is found. A mile or so to the south of the modern road the faint marks of an older trail may be seen. The old trail follows closely the line of an elevated strand 150 feet above the present level of the lake. Beside it lie piles and lines of stones, such as are built beside all roads in this part of the lofty plateau of Bolivia. Several stone corrals are located at the roadside in highly exposed situations close to little valleys which are always dry, except during the few days when snow is melting or when a rare thunder-storm occurs. There is no grass anywhere along the road, nothing but bare gravel. There seems to be absolutely no reason for the location of a road along this line unless the climate of the past was such that the lake rose toward the level of the old strand, and that the now dry valleys contained running water which would give cause for the location of corrals beside them. If this were the case the position of the trail is highly sensible. It follows the shortest line

which was then possible; and the corrals are located at exactly the places where water would naturally be found, and in the only place where grass would be abundant, namely, in the strip close to the lake. Unless the climate of the past were different from that of the present, the location of the road, as Bowman says, is absurd.

The change from the old trail to the existing routes does not seem to have been immediate. On the contrary there must have been an intervening period when a road existed along an elevated strand of the lake which lies 50 feet above the modern level and 100 feet below the main old road. The top of the 50-foot beach, as Bowman puts it—

> Is criss-crossed by old and now somewhat faint llama trails. These have a peculiar braided pattern everywhere, an unmistakable design caused by the irregular march of this erratic beast as it wanders this way and that from the general route. Not even a vagrant llama would follow the route to-day because of the absence of food as contrasted with its presence on the alluvial slope and basin floor just below. Much less would such a course be followed by a caravan. The consideration of changing lake level having temporarily forced the road to this higher level in response to cyclic climatic changes of short duration, is excluded because these fluctuations are but a few feet in value at the most, as marked by the saline deposit that the waters form and is indicated by the fact that the corrals, huts, and trails now in use are at various intermediate levels between the 50-foot beach and the basin floor. While one must admit less certainty in this case than in the other, it is again a much more reasonable view that the trails were made at a time when the lake waters stood near the level of the old beach and no better course could be found by the traveler than the relatively flat-topped beach, rough and stony as it is.

Similarity of phenomena of desiccation in the Old World and the New World.

The American phenomena described in the preceding pages are closely similar to phenomena of the same nature in Asia. For instance, the ancient strands of Great Salt Lake are of the same sort as those of the Caspian Sea, Lop Nor, and the lake of Seyistan. The Zuni ruins of New Mexico are closely comparable with scores of waterless ruins in Persia, Transcaspia, and Chinese Turkestan. The apparent decrease in the size of Lake Tezcuco during the last five centuries appears to have taken place synchronously with a similar decrease in the size of Lop Nor, the lake of Seyistan, and other Asiatic lakes. The terraces of Lima and the unwatered fields in Argentina and Bolivia, described by Moreno, present the same characteristics as the so-called Ghorband, or abandoned, unirrigated terraces and fields in the driest parts of Baluchistan. Darwin's huts and small village sites are almost identical in nature with old shepherds' huts and little agricultural villages whose ruins are now found in the Kuruk Tagh, or Dry Mountain region of far western China. (See fig. 3.)

In the case of the old roads and strands of Lake Huasco in Bolivia and Lop Nor in Chinese Turkestan, the similarity is almost startling. In both cases the modern road follows a direct route thru what was once a part of the bed of the lake. Above each modern road lie two ancient roads. One runs along a fairly well-marked strand indicating a relatively slight change in the dimensions of the lake. The other, a much more important road, lies along a strand which is located higher than the preceding and which indicates a much greater expansion of the water. The upper road in both cases is plainly marked by the customary piles of stones. All four roads, two in the middle of South America and two in the heart of Asia, are utterly inexplicable and are absurdly located, unless it be supposed that the climate of both continents has been subject to cyclic changes of considerable magnitude. (See figs. 1 and 2.)

A careful review of the phenomena described in the preceding pages and of other facts not here set forth, makes it hard to avoid the conclusion that the climatic histories of the continental regions of the Old World and the New World have been essentially the same. Cyclic changes appear to have been the rule; but the cycles have been of varying lengths, and have given rise to varying degrees of aridity, warmth, and the other elements which together constitute climate. On the whole, there seems to have been an increasing degree of warmth and aridity.

III. GENERAL CONCLUSIONS.

The cause of climatic changes.—It is beyond the province of this article to discuss at any length the problem of the cause of changes of climate. Nevertheless there are two points which spring naturally from the preceding discussion. In the first place, if the conclusions of this article are valid, there is no gap between the great climatic cycles of the glacial period on the one hand, and the small 11-year or 36-year cycles of the present day on the other hand. Between the two there are other cycles, the so-called "stages" which are known to have characterized the final phases of the glacial period and the briefer, but from the human standpoint more important, cycles of the historic period, the whole forming one great series. The small cycles of 11 or 36 years appear to be of the same nature as the large cycles, historic or glacial, so far as can be judged from their effects. The only difference appears to be in magnitude. This suggests that the cycles of all kinds may be due to a common cause. In the second place the change in temperature which students of the glacial period consider necessary in order to induce glaciation, is slight. Changes of a few tenths of a degree in a century appear at first thought to be of little importance, but geologists and students of the physics of the earth hold that such changes are capable of producing momentous results.

Various investigators, among whom Brückner,[7] Bigelow,[8] and the Lockers[9] hold a foremost place, believe not only that small climatic cycles exist with periods of from 3 to 36 years, but also that the cycles have a definite relation to variations in the activity of the sun. The solar variations are indicated by changes in the number and size of sun-spots or in the rapidity with which one sun-spot maximum succeeds another. Another set of investigators, among whom the most noteworthy are Langley and Abbott,[10] Köppen,[11] and Newcomb,[12] have studied the temperature of the earth's atmosphere in relation to changes in the sun. They have all concluded that the mean temperature of the earth varies in response to variations in the amount of heat received from the sun. Their figures differ markedly, but all agree that the amount of radiation from the sun actually varies.

Newcomb's study of the relation of the temperature of the sun to that of the earth is the most recent, comprehensive, and accurate that has ever been made. His conclusions are so careful and conservative that they can scarcely be doubted so far as they are based directly upon statistics. He expresses himself thus (p. 379): "A study of the annual departures [from mean temperature] over many regions of the globe in equatorial and middle latitudes, shows consistently a fluctuation corresponding with that of the solar spots. The maximum fluctuation in the general average is 0.13° C. on each side of the mean for the tropical regions. [The maximum temperature coming at times of minimum sun-spots]. The entire amplitude of the change is therefore 0.26° C. [0.47° F.], or somewhat less than half a degree of the Fahrenheit scale." On an earlier page (341) he says: "Altho the reality of this 11-year fluctuation [both solar and terrestrial] seems to be placed

[7] E. Brückner: Klimaschwankungen seit 1700.

[8] F. H. Bigelow: The relations between the meteorological elements of the United States and the solar radiation. Am. Jour. Sci., 1908, **25**: 413–430. Also Monthly Weather Review, various articles, 1902–1905.

[9] N. and W. J. S. Lockyer: Nature, 1901, **64**: 196–197. Proc. Roy. Soc., 1901, **69**: 285–300; and 1902, **70**: 500–504.

[10] S. P. Langley: On a possible variation of the solar radiation and its probable effect on terrestrial temperatures. Astrophysical Journal, 1904, **19**: 305–321.

[11] Köppen: Zeitschrift der Oesterreichischen Gesellschaft für Meteorologie. VIII Band. 1873.

[12] Simon Newcomb: A search for fluctuations in the sun's thermal radiation thru their influence on terrestrial temperature. Trans. Am. Philos. Soc., Philadelphia, 1908, **21** (n. s.): 309–387.

beyond serious doubt, the amplitude being several times its probable error, its amount is too small to produce any important direct effect upon meteorological phenomena." Again, on page 384 he puts in italics the last part of the following quotation: "It follows as the final result of the present investigation that *all the ordinary phenomena of temperature, rainfall, and winds are due to purely terrestrial causes, and that no changes occur in the sun's radiation which have any influence upon them.*"

While Newcomb's conclusion as to the change of temperature between the times of maximum and minimum sun-spots rests upon unassailable evidence, his last conclusion as to the relation of the changes to meteorological phenomena is based purely on inference and is open to question. He has failed to consider the effect which a slight change of temperature may have upon meteorological conditions provided it be permanent. In his 11-year cycle the range of temperature is 0.26° C. In order to estimate the true importance of such a variation, it is necessary to consider what would be the result if the temperature no longer fluctuated back and forth between the two extremes every eleven years, but remained constant at one extreme for a few centuries and then at the other for a corresponding length of time.

In order to explain the glacial period, geologists and students of "paleo-meteorology" postulate a change of the mean temperature of the earth's atmosphere many times larger than Newcomb's change in the 11-year cycle, but not of a different order of magnitude. Penck, the leading German student of glaciation, believes that a permanent change of 5° C. in temperature is sufficient to account for the difference between the conditions of the glacial period and those of to-day.

According to Ekholm,[13] a lowering of the mean annual temperature to the extent of from 7° to 9° C. would cause the snow-line of the earth as a whole to descend 3,300 feet, and would lead to a revival of the glacial period. Bonney[14] says that during the glacial period the temperature of England was about 20° F. lower than it now is, and the mean temperature of the earth's atmosphere as a whole was from 15° to 20° F. lower than at present. Brückner states that a lowering of the earth's temperature to the extent of 3° or 4° C. would suffice to account for the phenomena of the glacial period. He considers that the change in temperature would be relatively slight in equatorial regions and great in polar regions. Finally David,[15] from a study of glaciation in Australia and other less familiar parts of the world, arrives at the conclusion that in order to explain the phenomena of the last great advance of the ice it must be assumed that the temperature of that time was lower than that of the present by "probably not less than 5° C."

The mean value of the decrease in temperature necessary to produce a glacial period, according to the statements of the five authorities cited above, amounts to from 5° to 6° C. That is, if the mean temperature of the earth were to fall 5° or 6° C., and were to remain thus low for a sufficient length of time, meteorological conditions would be so altered that most of North America would be shrouded with ice down to about the fortieth degree of latitude, and Europe would suffer a corresponding glaciation. If a change of from 5° to 6° C. would produce such a result, it seems reasonable to suppose that the change of 0.26° C. which Newcomb has determined in the 11-year sun-spot cycle would produce a corresponding result on a smaller scale, provided the duration of the period of low temperature were long enough. To take a specific case for illustration, the Rhone glacier[16] is now barely 6 miles long; the foot of the ice stands at a height of 5,780 feet above sea-level, and the surface of the ice at its origin is 10,200 feet above the sea. During the period of maximum glaciation the glacier was 240 miles longer than it now is; its foot stood about 4,700 feet lower than is now the case, and its surface near the origin was 1,400 feet above the present surface. For the sake of conservatism, let it be assumed that the change of temperature necessary to cause the Rhone glacier to assume its former great dimensions was 13° C., which is greater than the maximum figure given above (Bonney's, 20° F., or 11.1° C.), and more than twice the mean of the five authorities cited. Then a change of 0.26° C. would be one-fiftieth of the change necessary to cause the Rhone glacier to assume the dimensions which it had during the glacial period. It seems fair to assume that the results of a small change of temperature would be approximately proportional to those of a larger change. If this is so, the difference of 0.26° C., which Newcomb finds between the mean temperature of periods of minimum sunspots and those of maximum sunspots would cause pronounced changes in the Rhone glacier, provided the low temperature lasted long enough to allow of the abundant accumulation of snow. In that case, if the form of its valley were favorable, the Rhone glacier might become 5 miles longer than it now is; or, if the gradient of the valley bottom be assumed as uniform, the ice might descend 90 feet below its present level; or the glacier might increase 28 feet in thickness. The exact nature of the change in the glacier, and its exact dimensions would depend upon the topography of the Rhone Valley and upon the relation of precipitation to temperature, but the figures which have just been given show the order of magnitude of the results which would be effected by a permanent lowering of the mean annual temperature of the earth to the extent of 0.26° C. A change of temperature capable of producing such results or even results one-half as great can scarcely be said to be too small to produce "any important effect upon meteorological phenomena."

In conclusion it seems reasonable not only to conclude with the astronomers that at the present time the sun is subject to cyclic variations having a period of eleven years, but also that the variation in an average cycle is sufficient to cause changes in meteorological phenomena so important that if given time they would produce marked results. The effects of small cycles apparently differ only in magnitude from those of the historic cycles whose existence is indicated by abundant evidence both in Eurasia and in America; and these in turn are of essentially the same nature as the cycles of the glacial period. If the small changes of the 11-year cycles are due to variations in the intensity of the sun's radiation, there seems to be no reason why the large changes of past times may not be due to the same cause. As yet there is no evidence whatever to prove that the intensity of solar radiation does or does not fluctuate in periods of long duration. The radiation of other stars, however, is known thus to fluctuate. It is a fair working hypothesis that the sun is a variable star which in the course of great geological ages has past thru changes of every degree, and that even now the climate of the earth still varies in harmony with the globe upon whose rays all movement and life depends.

[13] Quart. Journ. Geol. Soc. of London, 1902, 58:39.

[14] Nature, 1903, 67:150.

[15] Congrès Geologique International. Compte Rendu de la X^eme Session. 1906. p. 468.

[16] Jas. Geikie: The Great Ice Age. 3d edition. 1894. p. 543 ff.

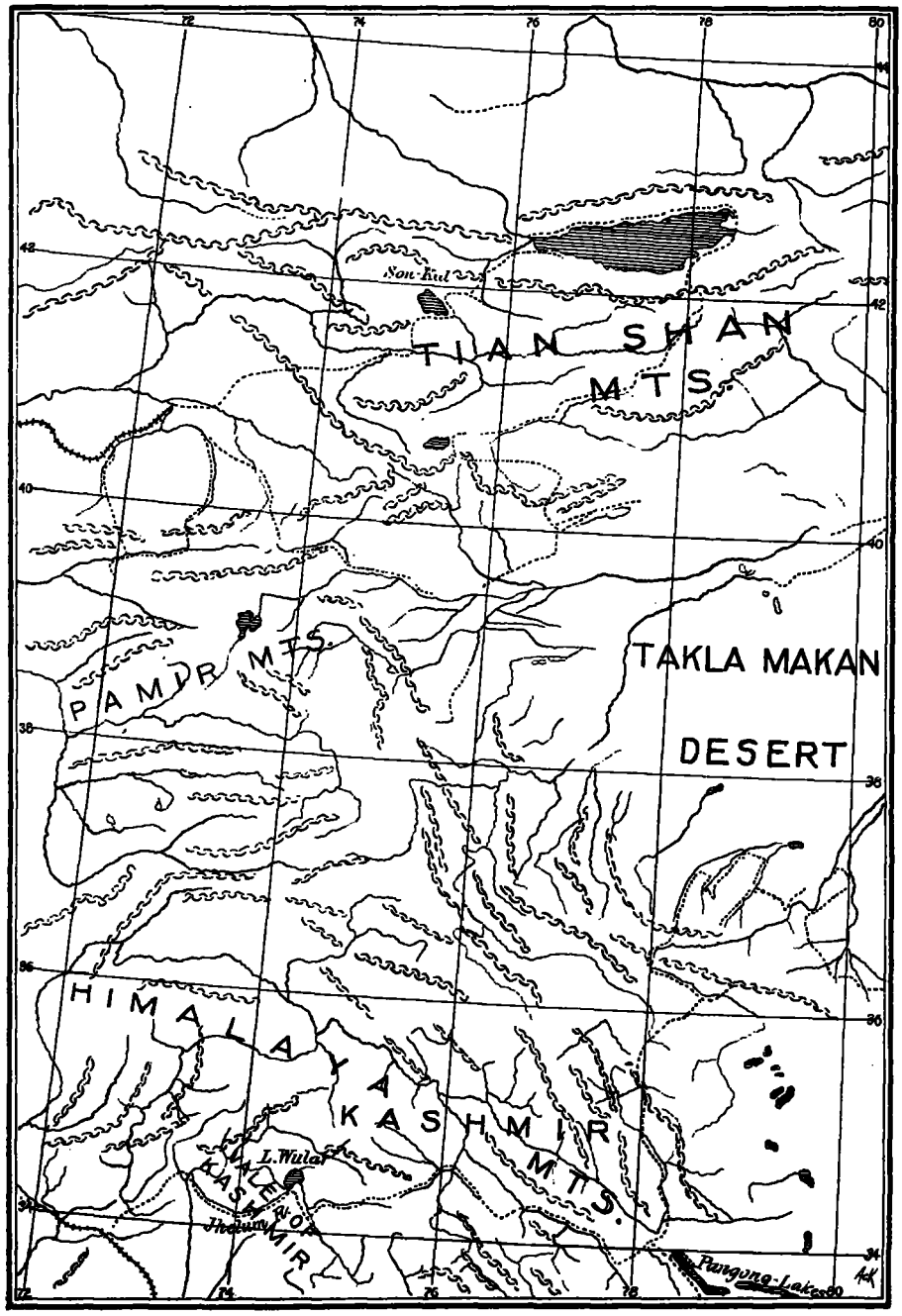

FIG. 1.—The deserts and lakes of central Asia. (See p. 449.)

..... Routes followed by Ellsworth Huntington.

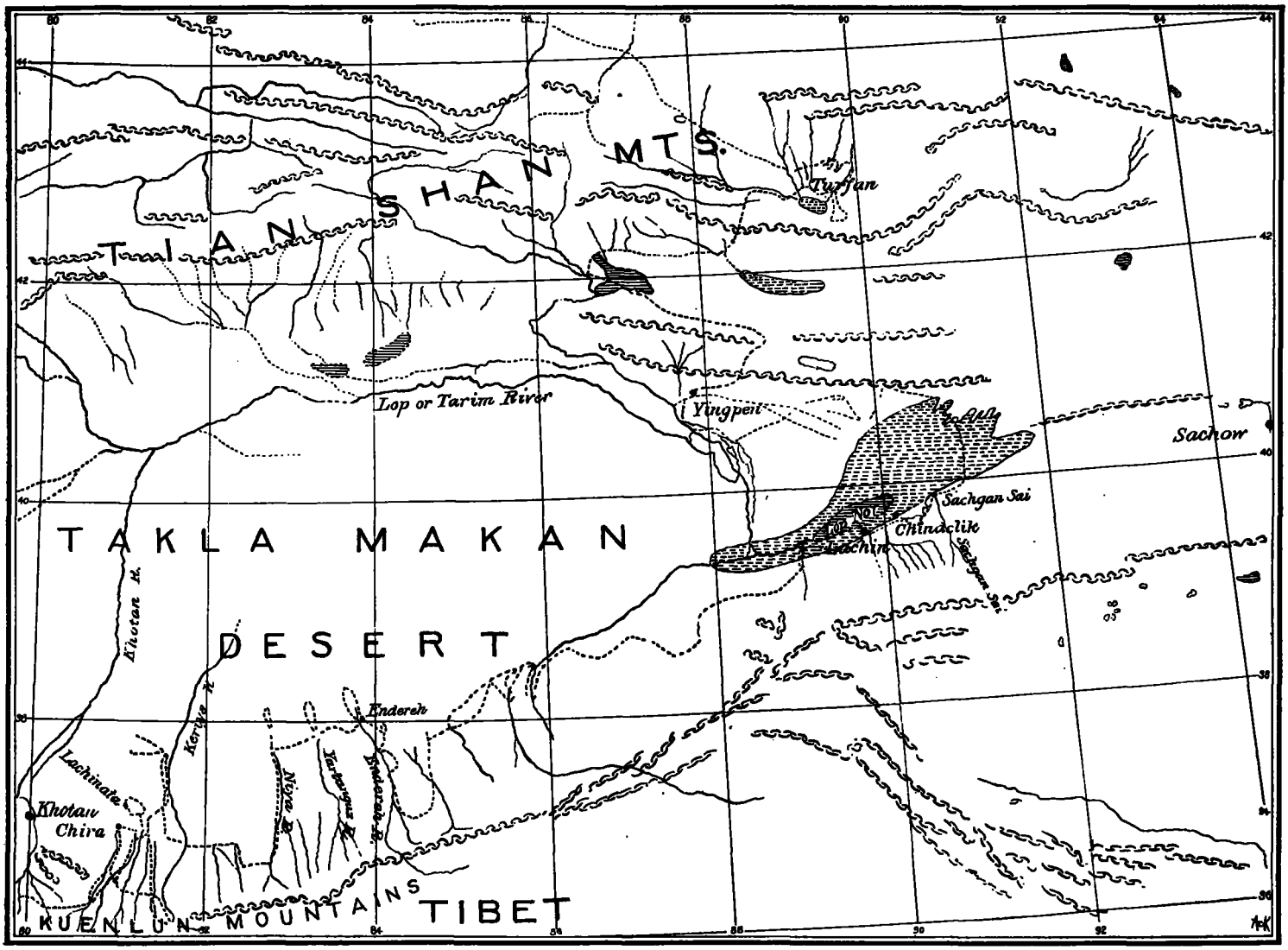

FIG. 2.—The deserts and lakes of central Asia. (See p. 449.)

..... Routes followed by Ellsworth Huntington.

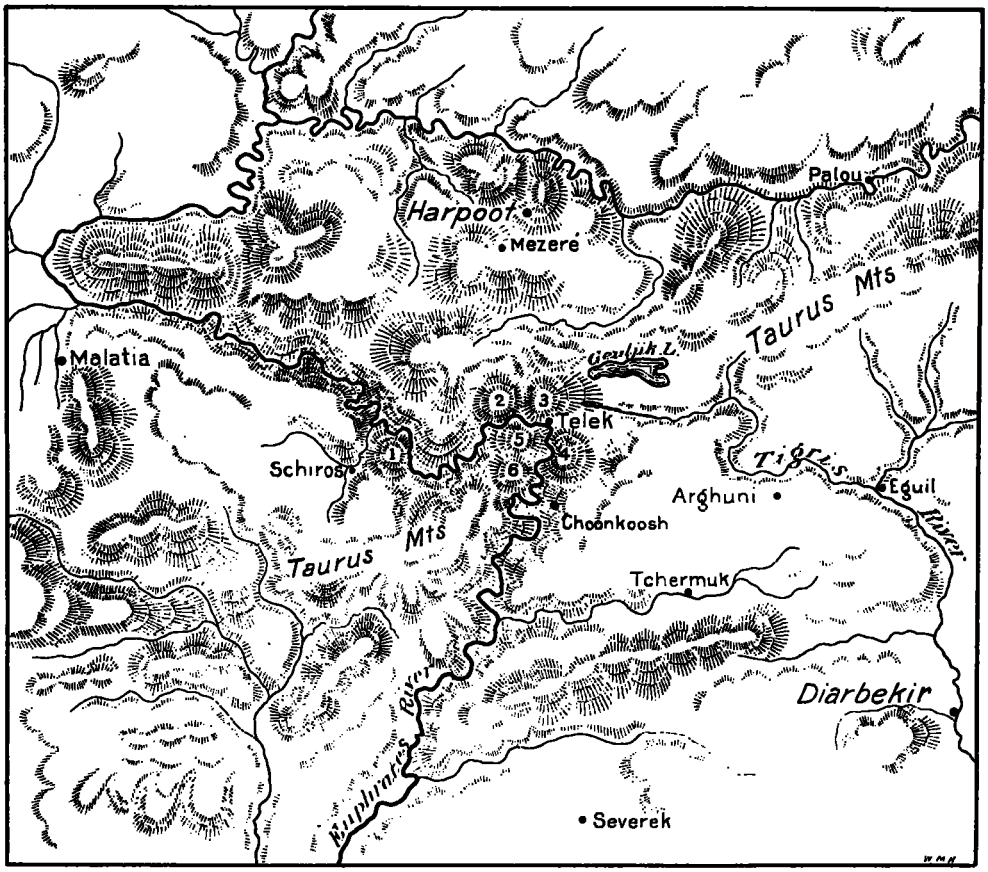

FIG. 3.—Location of Lake Geuljik, or Gyul-jük, in Asia Minor. (See p. 449.)